THE STATUS OF ANCIENT MURRELETS BREEDING ON LANGARA ISLAND, BRITISH COLUMBIA, IN 1988

Douglas F. Bertram

TECHNICAL REPORT SERIES No. 59
Pacific and Yukon Region 1989
Canadian Wildlife Service

Environment Canada
Canadian Wildlife Service

Environnement Canada
Service canadien de la faune

Canada

89-04211/

TECHNICAL REPORT SERIES
CANADIAN WILDLIFE SERVICE

This series of reports, established in 1986, contains technical and scientific information from projects of the Canadian Wildlife Service. The reports are intended to make available material that either is of interest to a limited audience or is too extensive to be accommodated in scientific journals or in existing CWS series.

Demand for these Technical Reports is usually confined to specialists in the fields concerned. Consequently, they are produced regionally and in small quantities; they can be obtained only from the address given on the back of the title page. However, they are numbered nationally. The recommended citation appears on the title page.

Technical Reports are available in CWS libraries and are listed with the DOBIS system in major scientific libraries across Canada. They are printed in the official language chosen by the author to meet the language preference of the likely audience. **To determine whether there is significant demand for making the reports available in the second official language, CWS invites users to specify their official language preference. Requests for Technical Reports in the second official language should be sent to the address on the back of the title page.**

SÉRIE DE RAPPORTS TECHNIQUES
DU SERVICE CANADIEN DE LA FAUNE

Cette série de rapports donnant des informations scientifiques et techniques sur les projets du Service canadien de la faune (SCF) a démarré en 1986. L'objet de ces rapports est de promouvoir la diffusion d'études s'adressant à un public restreint ou trop volumineuses pour paraître dans une revue scientifique ou l'une des séries du SCF.

Ordinairement, seuls les spécialistes des sujets traités demandent ces rapports techniques. Ces documents ne sont donc produits qu'à l'échelon régional et en quantités limitées; ils ne peuvent être obtenus qu'à l'adresse figurant au dos de la page titre. Cependant, leur numérotage est effectué à l'échelle nationale. La citation recommandée apparaît à la page titre.

Ces rapports se trouvent dans les bibliothèques du SCF et figurent aussi dans les listes du système de référence DOBIS utilisé dans les principales bibliothèques scientifiques du Canada. Ils sont publiés dans la langue officielle choisie par l'auteur en fonction du public visé. **En vue de déterminer si la demande est suffisamment importante pour produire ces rapports dans la deuxième langue officielle, le SCF invite les usagers à lui indiquer leur langue officielle préférée. Il faut envoyer les demandes de rapports techniques dans la deuxième langue officielle à l'adresse indiquée au verso de la page titre.**

Cover illustration is by R.W. Butler and may not be used for any other purpose without the artist's written permission.

L'illustration de la couverture est une œuvre de R.W. Butler. Elle ne peut dans aucun cas être utilisée sans avoir obtenu préalablement la permission écrite de l'auteur.

THE STATUS OF ANCIENT MURRELETS BREEDING ON LANGARA ISLAND, BRITISH COLUMBIA, IN 1988

Douglas F. Bertram

Technical Report Series No. 59
Pacific and Yukon Region 1989
Canadian Wildlife Service

This series may be cited as:

Bertram, Douglas F. 1989. The status of Ancient Murrelets breeding on Langara Island, British Columbia, in 1988. Technical Report Series No. 59. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Published by Authority of the
Minister of Environment
Canadian Wildlife Service

Minister of Supply and Services Canada 1989
Catalogue No. CW69-5/59E
ISBN 0-662-16827-5
ISSN 0831-6481

Copies may be obtained from:
Canadian Wildlife Service,
Pacific and Yukon Region
P.O. Box 340,
Delta, British Columbia,
Canada V4K 3Y3

ABSTRACT

A suspected long-term decline of the Langara Island Ancient Murrelet (Synthliboramphus antiquus) population was investigated between 6 May and 7 June, 1988. Survey results were compared to a previous census that employed the same estimation technique. The colony consisted of 63,000 +/- 10,500 (S.E.) burrows in 1988 versus 83,000 +/- 14,000 in 1981. Although the extent of the colony was less than half the size previously reported, burrow density was higher than in 1981. Burrow occupancy rates were similar in both surveys (26% in 1981 and 38% in 1988). The population estimate for 1988 was 24,100 +/- 4,000 (S.E.) breeding pairs compared to 21,500 +/- 3,600 in 1981. Problems with the accuracy of the census technique are discussed.

Twenty-nine percent of the burrows whose entire contents were searched (n=56) contained bones - a far greater percentage than for any other Ancient Murrelet colony in the Queen Charlotte Islands. Bones were most common in burrows in abandoned areas of the colony and least common where occupancy rate was high. The discovery of adult birds, apparently killed in their burrows by introduced Alexandrian rats (Rattus rattus alexandrinus), in combination with the high proportion of burrows with bones suggests that rats may have contributed to the decline of Ancient Murrelets on Langara Island.

RESUME

Une étude portant sur la diminution à long terme des populations d'Alques à Cou Blanc (Synthliboramphus antiquus) sur l Ile Langara fut conduite entre le 6 mai et le 7 juin 1988. Les résultats des recensements conduits en 1988 furent comparés à ceux de 1981 utilisant les mêmes techniques. 1981. La colonie compta 63,000 +/- 10,500 (écart type) terriers en 1988, comparativement à 83,000 +/- 14,000 en 1981. La colonie ne couvrit que moins de la moitié de la superficie couverte en 1981, mais la densité de terriers fut plus élevée. Le taux d'occupation des terriers fut semblable lors des 2 années (26% en 1981 et 38% en 1988). La population de couples nicheurs fut évaluée à 24,100 +/- 4,000 (ecart type) en 1988, comparativement à 21,500 +/- 3600 en 1981. La précision des recensements est également discutée.

Vingt-neuf pourcent des terriers dont le contenu fût analysé (n=56) continrent des os. Ce pourcentage est beaucoup plus élevé que pour n'importe quelle autre colonie d'Alques à Cou Blanc des Iles de la Reine Charlotte. Les os furent principalement observés dans les terriers situés dans les zones abandonnées de la colonie, et furent peu fréquents dans les zones à fort taux d'occupation. La découverte d'oiseaux adultes apparamment tués dans leurs terriers par des rats noirs d'Alexandrie (Rattus rattus alexandrinus) de même que la forte proportion de terriers contenant des os semblent indiquer que les rats puissent être responsables du déclin de la population d'Alques à Cou Blanc sur l'Ile Langara.

ACKNOWLEDGEMENTS

This work was made possible through the diligent efforts of the following field workers, some of whom were volunteers (†). H. Hay, K. Henderson†, N. Holmes, G. Kaiser, M. McKay†.

I am indebted to the staff at the Canadian Coast Guard base at Seal Cove, Prince Rupert, in particular to V. Skinner for arranging helicopter transportation for people and gear to and from Langara Island Light Station. Thanks to the light keepers on Langara, Ken Brunn, Lise Faurette, and "Rotten" Robert, who provided logistic support and warm hospitality.

I thank the Massett Band Council for permission to work on the Indian Reserve at Cohoe Point. Keith Moore, formerly of the B.C. Fish and Wildlife Service (Q.C.I.), helped with logistic support on short notice.

I benefitted from conversations with Drs. A.J. Gaston and R.C. Ydenberg before entering the field. Dr. B.T. Collins provided a copy of the computer program 'CIIR'. L.S. Forbes, G. Kaiser, M. Rodway, Dr. J.P. Savard, and S. Wetmore helped improve drafts of this manuscipt. Sandi Bertram did the typing. I am grateful to all of them.

TABLE OF CONTENTS

Abstract ii

Resume iii

Acknowledgements iv

1. INTRODUCTION 1

2. METHODS 3

2.1 Study site 3

2.2 Census technique 3

2.3 Knock-down plots 5

2.4 Staging count 7

2.5 Chick funnel and departure weights 7

2.6 Egg measurements 8

2.7 Predation 9

3. RESULTS 12

3.1 Survey summary and population estimate 12

3.2 Knock-down plots 25

3.3 Staging count 28

3.4 Incubation initiation and chick departure weight ... 33

3.5 Predation 35

4. DISCUSSION 39

5. LITERATURE CITED 48

APPENDIX 1: Location of transects in 1981 50

APPENDIX 2: Location of transects in 1988 51

APPENDIX 3: Population estimate for 1988 53

APPENDIX 4: Raw data from knock-down plots 56

APPENDIX 5: Estimated date of the start of incubation 67

1. INTRODUCTION

Comparing the present size of animal populations to past populations for which no reliable census data exist is a difficult problem that often faces wildlife managers. Such is the scenario for the seabirds of Langara Island at the northwestern tip of the Queen Charlotte Islands, British Columbia (B.C.). Once one of B.C.'s largest seabird colonies (Drent and Guiguet 1961) Langara Island has lost its colonies of Cassin's Auklet (Ptychoramphus aleutica), Rhinoceros Auklet (Cerorhinca monocerata), Tufted Puffins (Lunda cirrhata), Fork-tailed Storm Petrels (Oceanodroma furcata) and Leach's Storm Petrels (Oceanodroma leucorhoa; [Royal British Columbia Museum (R.B.C.M) unpublished seabird survey data, 1977]). Ancient Murrelet, however, were the most abundant species on Langara (e.g. Green 1916; Darcus 1930) but have declined. Their numbers in the 1950's were described as "astronomical" (Beebe 1960) and "immense" (Drent and Guiguet 1961) however no objective estimates were placed on the population size.

Reduced food supply was proposed as the cause of the apparent dramatic decline of Ancient Murrelets on Langara in the 1950's and 1960's (Nelson and Myres 1976). During the early 1970's, Sealy (1976) conducted the first intensive study of the breeding biology of the species on Langara. Subjective estimates for the population size during that period ranged from 50,000 breeding pairs (Nelson and Myres 1976), to 80,000 or 90,000 breeding pairs (Vermeer et al. 1984). A Canadian Wildlife

Service survey conducted in 1981 (Rodway et al. 1983) estimated 22,500 breeding pairs. At that time, avian predators were thought to be a contributing cause of decline (Vermeer et al. 1984) while depredation by introduced rats, inferred by Sealy 1976, was considered to have had minimal impact (Nelson and Myres 1976; Sealy 1976; Vermeer et al. 1984)

The 1988 inquiry into the status of Peregrine Falcons (Falco peregrinus; Shelford 1988), a species whose decline on Langara has been linked to the decline of Ancient Murrelets (Nelson and Myres 1976), prompted the Canadian Wildlife Service to investigate the current status of the Langara murrelet population.

The objective of the study was to replicate the 1981 census and to investigate possible causes for the long-term decline. In addition, a number of aspects of the breeding biology were examined to facilitate future population monitoring and comparison with other colonies such as Reef Island, where Ancient Murrelets have been studied intensively since 1984 (Gaston et al. 1988).

2. METHODS

2.1 Study site

Langara Island (54° 12' N, 133° 1' W at Iphigenia Point) is located in Dixon Entrance off the northwest tip of the Queen Charlotte Islands (about one km north of Graham Island). The island is approximately 40 km² and 9.5 km across at its broadest point. The island's flora and the nesting habitat of Ancient Murrelets has been described by Sealy (1976) and Rodway et al. (1983). A team of three visited Langara from 6 May - 7 June 1988. They were augmented by 3 additional surveyors from 12 May - 26 May. The camp was placed on the south side of McPherson Point, close to the middle of the colony described by Rodway et al. (1983).

2.2 Census technique

We repeated the transects conducted in 1981 (Appendix 1) in areas where birds were still nesting. (Note that the term transect refers to a compass bearing along which plots are laid at specific intervals). The transects were run along the same bearing (the declination was 27° N) and commenced at the same starting point listed in Rodway et al. (1983). In addition, we intensified survey coverage within the colony by running new transects in between the ones laid out in 1981 (transects were spaced 300 m - 500 m apart). Those transects were run

perpendicular to the shore. At 40 m intervals we counted the number of burrows in 5 m x 5 m plots. Burrows were distinguished from holes in the ground by reaching into them to check for signs of Ancient Murrelet nesting activity. Such signs (indicative of an active colony) included egg membranes, eggshell fragments, feathers, nest cups, fecal material or worn, flattened earth that had been trampled underfoot. Since not all burrows were active (i.e. contained a nesting pair) we determined occupancy rate by direct inspection of all burrows in every other quadrat along a transect. (We used this method on transects 1 - 10 but began sampling every quadrat on transects 11 - 16). Direct inspection of burrows often required excavation with a trowel and pruning clippers to cut through tree roots. Burrows subject to direct inspection were classified as occupied (an incubating adult, eggs, chicks or eggshell membrane and shell remains from freshly hatched eggs), unoccupied, or unknown (if the end of all tunnels could not be reached). In addition to counting the number of burrows in each quadrat, the elevation and aspect of the slope was recorded. Between quadrats the slope was measured using a clinometer and evidence of murrelet activity (burrowing, feather piles, depredated eggs) were noted to help delineate colony boundaries. When no active burrows or other signs of activity could be found in a quadrat, or the area halfway towards the surrounding quadrats, that area was not considered to be part of the colony.

Areas classified as colony by Rodway et al. (1983) were not transected if signs of active burrowing could not be found in

that area. Abandoned areas were explored on foot however, to determine if small 'pockets' were still active. If pockets were discovered the number of active burrows were conservatively estimated.

The number of breeding pairs was estimated using the same methodology as Rodway et al. (1983) with one minor exception. Instead of tallying the total number of burrows and dividing by the number of quadrats to obtain a value for burrow density, I used the burrow density in each quadrat to obtain mean and S.E. estimates of burrow density. This allowed an error term to be assigned to the population estimate. To make the two surveys comparable I recalculated Rodway et al.'s (1983) estimate in a similar fashion.

2.3 Knock-down plots

Following the methodology outlined by Gaston and Collins (1988) we examined burrow visitation rate by placing tooth picks or wooden matches at the entrance of 338 individually marked burrows and monitored knock-downs for 15 consecutive days between 15 and 30 May. The burrows were distributed in three pairs of 20 m x 20 m plots at three well separated locations throughout the colony (see Figure App.4.1). Burrows with more than one entrance were tooth-picked at all entrances. Burrows were identified using the same criteria as described in section 2.2. Observers were careful not to disturb incubating birds in order to prevent desertion.

At the end of the 15 day monitoring period a 25% section (10 m x 10 m) from each of four of the knock-down plots was excavated to allow direct inspection of burrows. One of pairs 1 and 2, and 5 and 6 were chosen randomly and both knock-down plots 3 and 4 (not personally erected by the author) were chosen for excavation. The section to be excavated from each plot was chosen at random. We carried out this procedure for the following reasons: a) to examine how successful observers had been at identifying burrows in the plot (i.e. were any burrows missed or were any improperly tagged?); b) to examine how knock-down rate relates to burrow occupancy status (occupied/unoccupied); and c) to establish an estimate of occupancy rate for high density nesting areas. (Note that due to the subjective positioning of the knock-down plots, this information was not used to estimate the overall colony burrow occupancy rate).

As Gaston and Collins (1988) point out the knock-down rate cannot be used to determine the occupancy rate since prospecting birds commonly enter burrows at night, presumably looking for a place to breed in following years. The technique allows researchers to examine changes in the rate of knock-downs from year to year and enables them to make conclusions with known probability.

2.4 Staging count

Ancient Murrelets commonly form large rafts on the ocean adjacent to the colony before coming in at night. This behaviour is known as staging. Rafts are composed of both breeding and non-breeding birds. There is night-to-night variation in the number of arrivals at the colony and these fluctuations are believed to be largely due to non-breeders. Thus, the relative number of non-breeders can be gauged by counting birds on the staging area. For ten minutes each night, two hours before sunset, I counted the number of staging birds flying through the field of view of a telescope (24 mm x 80 mm; Gaston, pers. comm.). Observations were conducted on the west shore of the south bay on McPherson Point with the telescope on a bearing of 52°, looking just above the rocks on the south end of McPherson Point.

2.5 Chick funnel and departure weights

In a valley west of the north bay on McPherson Point we constructed a plastic-walled funnel to herd departing chicks into one site (Gaston et al. 1988). The clear plastic funnel walls were approximately 80 cm high and the bottom of the wall was secured to the ground with rocks and sticks to prevent chicks from escaping underneath. Unable to leap over the walls, the chicks were forced to move along the funnel (the other wall was the steep edge of the valley) to an exit hole that had been

fitted with an electronic counting device. Each time a chick passed through the funnel exit an infra-red beam was broken and the counter registered another unit on memory.

Chicks coming through the funnel were periodically weighed (between 00:00 hrs and 02:00 hrs) to investigate how weight changed with date of burrow departure. Chicks were detained in cloth bird bags for less than 5 minutes and weighed to the nearest 0.5 g with a 100 g Pesola spring balance. After weighing, chicks were released along the shore, close to the funnel mouth.

2.6 Egg measurements

Since we were not present in the colony during April, laying date was estimated (mean +/- S.E.) using an algorithm ('CIIR') developed by Collins and Gaston (1987; see Collins 1987 for the documentation on 'CIIR'). Once the relationship between egg density and the rate of weight loss during incubation has been established for a species (the standard equation), an estimate of laying date can be obtained given a sample of eggs whose density (length x breadth/width) and measurement dates are known. The standard equation for Ancient Murrelets was derived by A.J. Gaston (pers. comm.).

We measured the length and breadth of eggs to the nearest 0.1 mm using vernier calipers, and determined weight to the nearest 0.5 g with a 100 g Pesola spring balance. Only one egg

from each clutch (the first one discovered) was measured.

When pipping eggs were discovered, we assumed a 32 day incubation period (Collins and Gaston 1987) and thus calculated laying date by subtracting that number from the date of discovery.

2.7 Predation

When transecting, we recorded Ancient Murrelet feather piles (left by avian predators), depredated eggs, spruce cone chewings (assumed to be left by rats) and incidences of bones or dead birds in burrows. Ancient Murrelet skulls found in burrows were identified as chewed (if they appeared to have had the cranial case opened in a way other than by deterioration) or intact. We did not begin this latter procedure until 17 May when the high frequency of skeletal remains in burrows became evident. It is noteworthy that there are no other mammals on Langara Island, such as squirrels or mice (Cowan and Guiguet 1965), that might be responsible for the spruce cone or skull chewings.

Feather piles and depredated eggs were also recorded in the knock-down plots. During the direct inspection of burrows in those plots we also noted contents attributed to predation (bones, etc.).

We placed 10 Woodstream snap rat traps at locations close to McPherson Point that appeared to be used by rats - worn paths under logs or worn areas where there were spruce cone chewings

and/or rat dung. The traps were placed at varying distances from the shore line (10 m - 80 m) although most were placed within 30 m of the vegetation edge. Some traps were placed in the colony, which tended to lie about 50 m from shore and approximately 30 m above sea level. Other traps were placed on the periphery of the colony in areas where abandoned burrows and signs of rat activity were found.

At first we baited the traps with peanut butter but later tried a mixture of peanut butter and cheese and finally hamburger grease mixed with herring. Traps were attached to a short string tied to a 15 cm spike firmly implanted in the ground. We checked traps regularly for specimens which were collected and later frozen. Since traps appeared to be sprung regularly we repositioned them or placed a cardboard housing over them to allow investigating rodents to approach from only one direction.

In addition to the snap traps, three live treddle traps were baited with chicken leftovers and placed at, or near, the vegetation edge of the bay on the west side of McPherson Point.

To investigate the fate of unattended clutches, we placed pairs of chicken eggs (an experimental clutch) in 13 empty burrows. The burrows selected were in areas where spruce cone chewings (presumably left by rats) were located and in one area where a rat had been trapped. In each experimental clutch one egg was carefully cracked (with a light blow from the edge of a knife), the other was left intact. This was done to see if

cracked eggs were more susceptible to depredation than intact eggs. The two eggs in each clutch were placed together at the end of empty burrows on twigs. After initiating the experiment on 17 May the clutches were inspected every 3 days until our departure.

3. RESULTS

3.1 Survey summary and population estimate

We surveyed 108 quadrats spread along 16 transects on the northeast side of Langara Island (Figure 3.1, see Appendix 2 for details of locations). Eight of those transects were run as replicates of the 1981 survey (Rodway et al. 1983), the others were in new locations. Since the previous survey, the extent of the colony has diminished. The area behind the camp (McPherson Point) covered by transects 13 and 14 was abandoned. Although an area of active burrows was found around transect 4 there was no sign of nesting Ancient Murrelets on the remaining transects south of McPherson Point.

Table 3.1 summarizes the results of the survey. (Note that the complete survey data set will be included in a forthcoming technical report of this series covering seabird colonies on the west coast of Graham Island). We discovered 160 burrows in the 108 quadrats examined. However, we could only reach to the end of 56 (35%) of those burrows. Occupancy rate of burrows ranged from zero in abandoned areas to 67% on transect 9. Within the colony, the overall estimated burrow occupancy rate was 38% (Table 3.1)

Many of the burrows examined contained skeletal remains of adult Ancient Murrelets. While some transects had no burrows with bones, others had bones in 60% of the burrows examined. Of

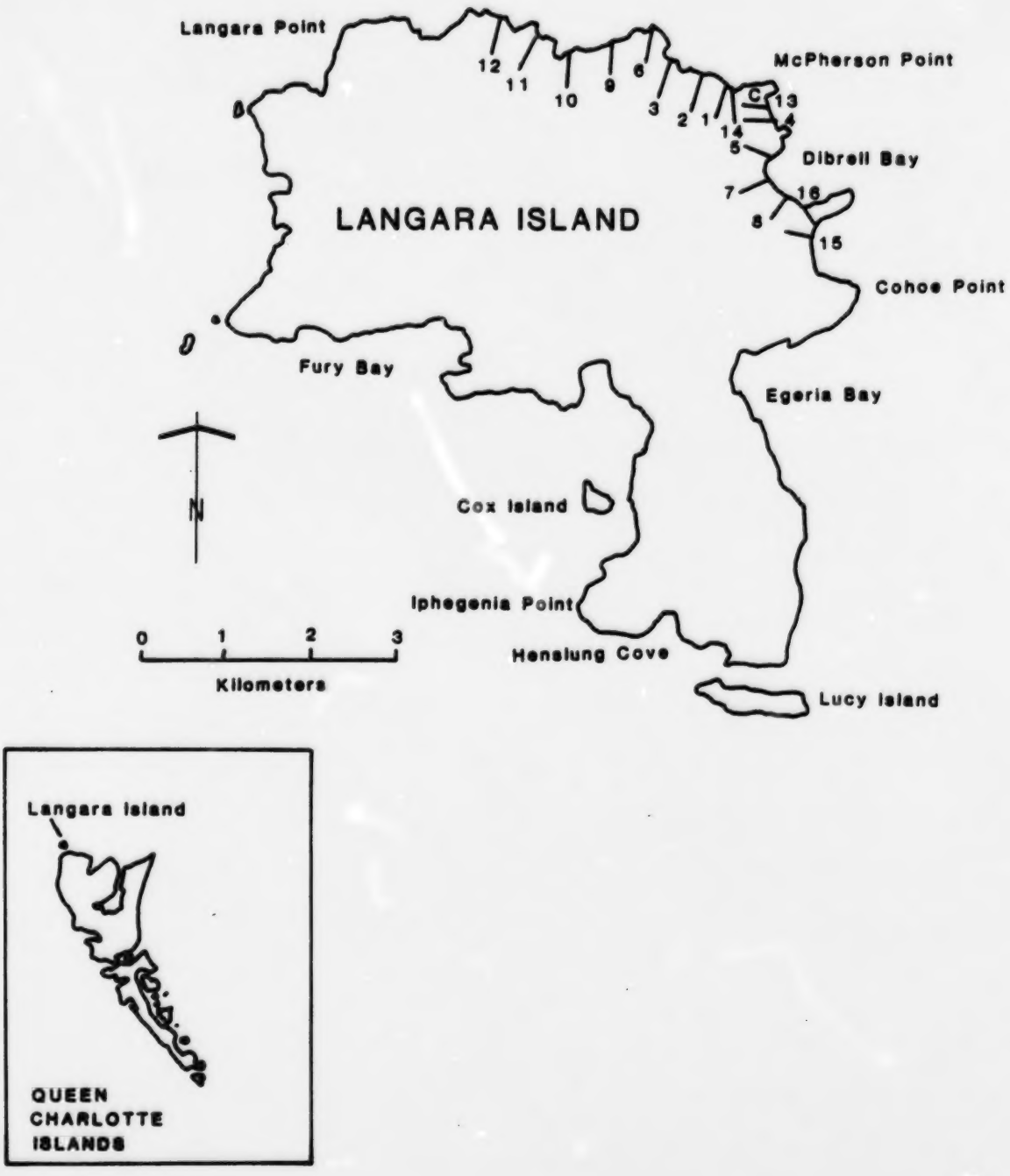


Figure 3.1: The location of Langara Island in the Queen Charlotte Islands and the placement of transects performed in 1988. The location of the camp (C) at McPherson Point is also shown.

Table 3.1: Burrow occupancy rate and related information collected from transects (Trans) run on Langara Island during May, 1988. The number of burrows represents the sum total of burrows found in quadrats along a transect. Occupancy rate was calculated using only burrows whose entire contents were searched. Status (Stat) refers to the presence or absence of active nesting along a transect (A = abandoned, C = colony). The proportion of burrows containing bones is presented in two ways: 1) for all burrows found, and 2) for burrows whose ends were reached. Fp = feather piles; De = depredated eggs; Sc = spruce cone chewings found in quadrats (Y = yes; N = no). * = not available.

Trans	Stat	Number of burrows	Burrow ends reached	Occ. rate	Proportion of burrows with bones: All burrows	Proportion of burrows with bones: End reached	Fp	De	Sc
12	A	1	1	0.00	0.00	0.00	0	0	Y
11	A	5	5	0.00	0.60	0.60	0	0	Y
10	C	7	4	0.25	0.43	0.50	1	0	N
9	C	14	3	0.67	0.00	0.00	0	2	Y
6	C	11	0	*	0.09	*	1	2	N
3	C	23	2	0.33	0.00	0.00	3	1	Y
2	C	18	7	0.42	0.00	0.00	3	3	Y
1	C	23	3	0.50	0.13	0.00	0	2	Y
14	A	12	9	0.00	0.33	0.44	1	0	N
13	A	22	10	0.00	0.27	0.20	0	0	Y
4	C	9	7	0.29	0.33	0.29	3	1	Y
5	A	0	*	*	*	*	0	0	N
7	A	7	4	0.00	0.43	0.75	0	0	Y
8	A	7	1	0.00	0.14	0.00	0	0	Y
16	A	1	0	*	0.00	*	0	0	N
15	A	0	*	*	*	*	0	0	Y
Totals		160	56	0.38‡	0.17†	0.29†	12	11	

† Average value
‡ 10 occupied burrows out of 26 completely searched in the colony

the 160 burrows discovered 17% contained bones. This figure is likely an underestimate since many of those burrows (65%) were not completely searched. Using the 56 burrows whose ends were reached, we calculated that 29% of the burrows contained bones (Table 3.1).

On a given transect the proportion of burrows that contained bones was found to be dependent on the occupancy rate of burrows along that transect. As occupancy rate increased the proportion of burrows containing bones declined significantly ($\rho = -0.552$, d.f. = 16, $P < 0.02$; Figure 3.2). The highest proportion of bones occurred in abandoned areas of the colony (Table 3.1). During the execution of transects 7 through 16 we examined skulls found in burrows for signs of chewing. Of nine whole skulls found, the craniums of three appeared to have been chewed open, presumably by rats. Other skulls were either too decayed for their condition to be determined or the information was not recorded.

We counted 12 feather piles and 11 depredated eggs in the surveyed quadrats. These obvious signs of colony activity were more prevalent in areas where occupancy rate was high ($\rho = 0.66$, d.f. = 10, $P < 0.02$; Figure 3.3). Feather piles and eggshells were very rare in abandoned areas. (Table 3.1).

Spruce cone chewings were found on 11 of the 16 transects (Table 3.1). No two side by side transects were devoid of such chewings, suggesting that the animals responsible (rats) are present in a continuous band on the northeast coast of the

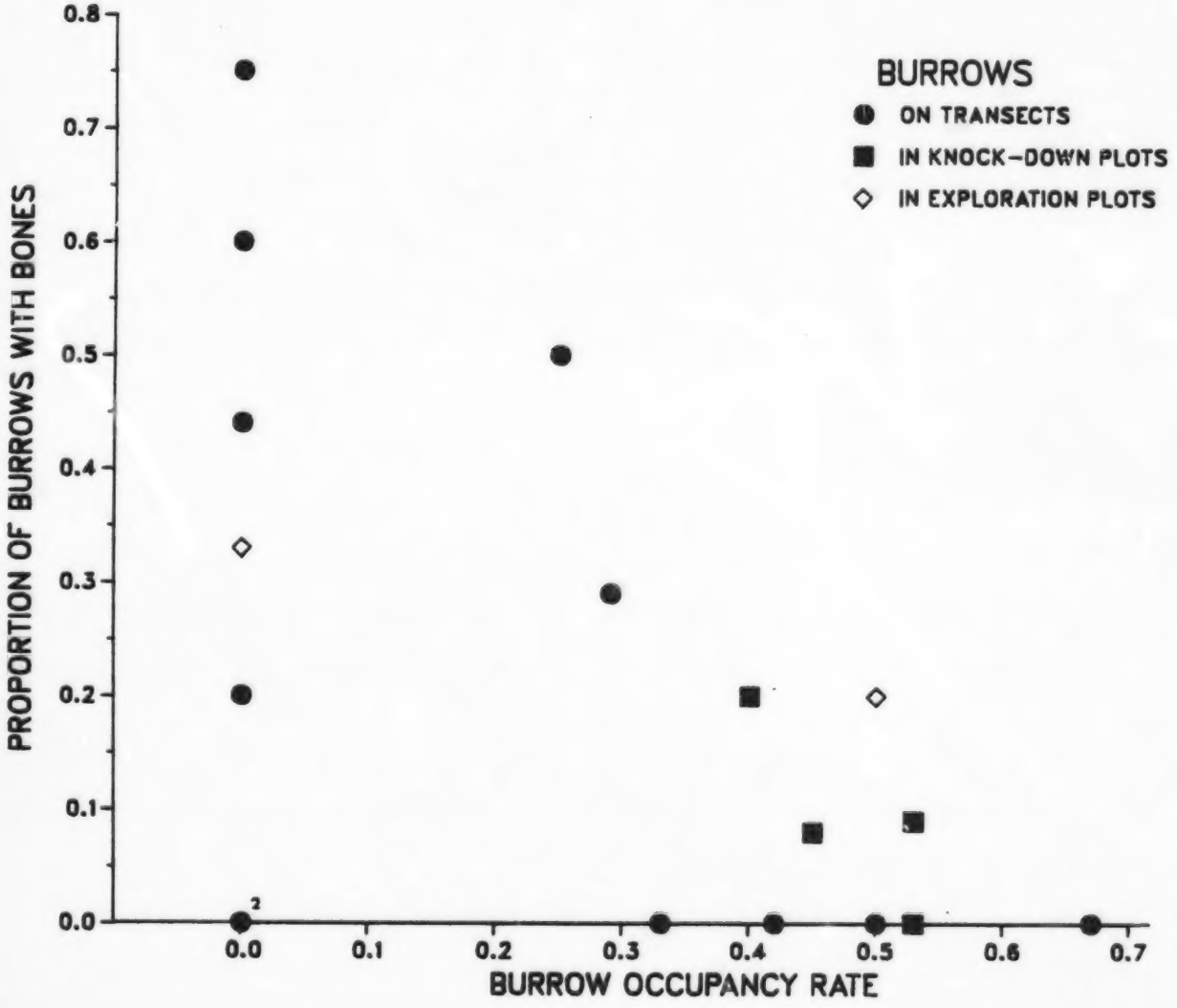


Figure 3.2: The relationship between burrow occupancy rate and the proportion of burrows containing bones (n = 18). All burrows were completely explored. The small 2 indicates two data points of that value.

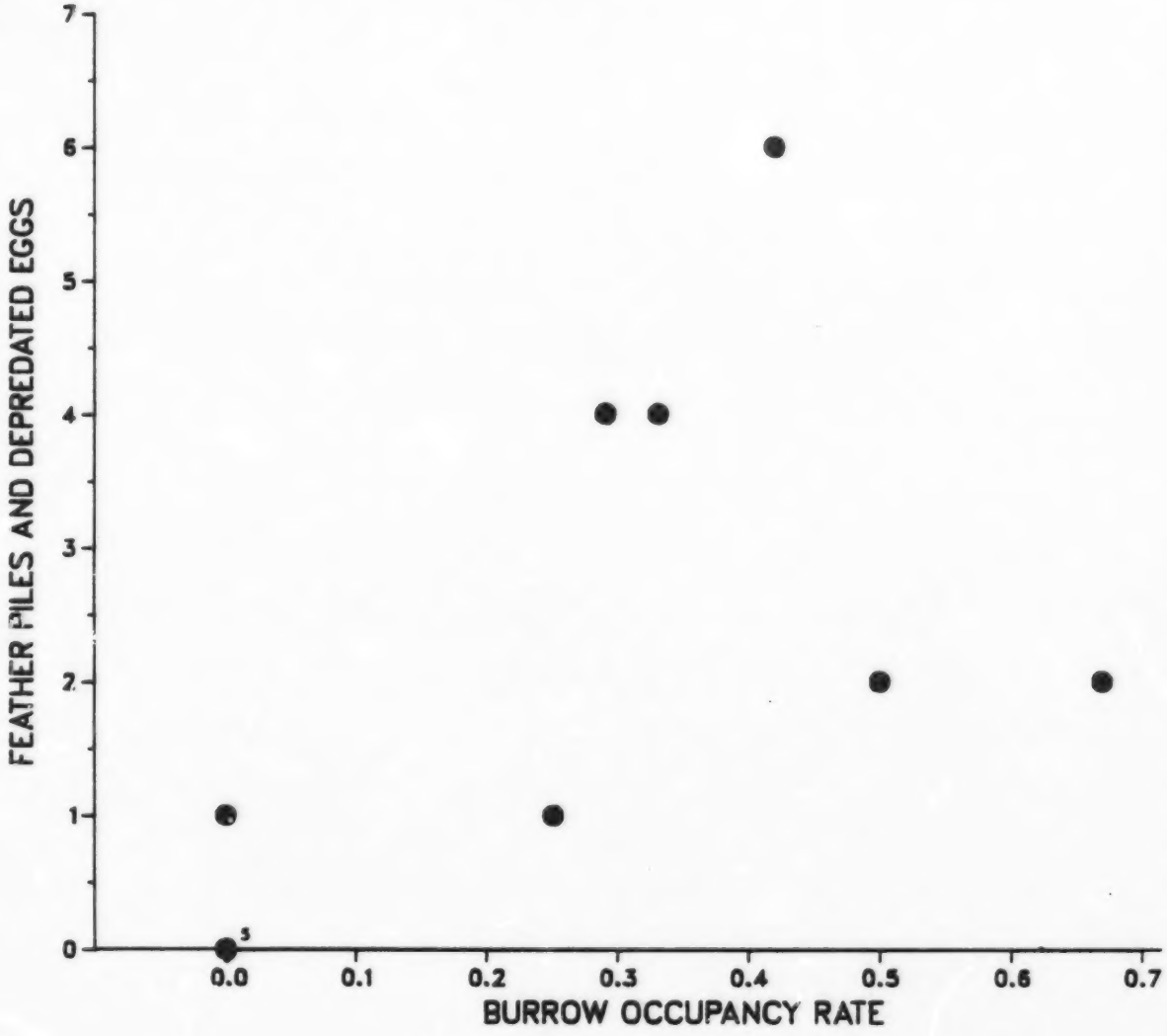


Figure 3.3: The relationship between burrow occupancy rate on a transect, and the number of feather piles plus depredated eggs found in quadrats along the same transect (n = 12). The small 5 indicates five data points of that value.

island.

Table 3.2a summarizes the results of burrow excavations in the knock-down-plots. Between 12 and 16 burrows were found in each of the 10 m x 10 m sections. We reached the ends of 47 (85%) of the 55 burrows discovered. They ranged in length from 0.2 m - 2.0 m and averaged 0.9 m. Occupancy rates in the plots were relatively high - the combined total for all four plots was 49% (Table 3.2). Four (9%) of the 47 burrows whose ends were reached contained bones (if all burrows were considered the proportion is 4/55 or 7%). One of three skulls found had been chewed open.

I explored the area south of transect 15 to Cohoe Point. No signs of recent nesting activity were found in Dibrell Bay although there were some obvious old, abandoned burrows. Spruce cone chewings were seen intermittently above ground and in a few old burrows that were checked. In an area that looked like part of the old colony, I excavated burrows in a 5 m x 5 m plot (plot A, Table 3.2, Figure App.4.1). Three empty burrows about 1 m long were found. One contained skeletal remains of an Ancient Murrelet.

In the south corner of Dibrell Bay, close to the area where the surveyors in 1981 ran their transect 11 (Appendix 1), I found a group of abandoned burrows. One had fresh rat dung at the entrance and spruce cone chewings inside. In another burrow I found what may have been an old rat cache - 5 skulls (all chewed), 2 sterna, various other bones, old eggshell and

Table 3.2: Burrow occupancy (Occ.) rate and related information collected from 10 m x 10 m knock-down plots (a) and 5 m x 5 m plots excavated near Cohoe Point (b). Status refers to the presence or absence of active nesting in the area (A = abandoned, C = colony). Occupancy rates were calculated using only burrows whose entire contents were searched.

a) Knock-down plots

Plot #	Stat	Number of burrows	Burrow end reached	Occ. rate	Proportion of burrows with bones: All burrows	Proportion of burrows with bones: End reached	Burrow length (m): Mean	Min	Max
1	C	14	13	0.53	0.00	0.00	0.9	0.5	2.0
3	C	12	10	0.40	0.17	0.20	1.0	0.3	1.8
4	C	16	13	0.53	0.08	0.09	1.0	0.2	2.0
5	C	13	11	0.45	0.06	0.08	1.1	0.6	1.5
Total		55	47	0.49†	0.07†	0.09†	0.9†	0.2	2.0

† Average value

b) Exploratory plots

Plot	Stat	Number of burrows	Burrow end reached	Occ. rate	Proportion of burrows with bones‡	Burrow length (m): Mean	Min	Max
A	A	3	3	0.00	0.33	0.9	0.8	1.0
B	C	10	10	0.50	0.20	0.7	0.5	1.0

‡ All burrows found were completely searched

eggshell membrane.

As I approached Cohoe Point, I began to see signs of Ancient Murrelet activity - feather piles, depredated eggs and droppings. Spruce cone chewings were also seen at regular intervals. Near the shore, on the north side of the tip of Cohoe Point, I found an area of very dense, active burrows at the top of a steep incline. On a level area that looked representative I excavated the burrows in a 5 m x 5 m plot (B, Table 3.2, Figure App.4.1). It contained 10 burrows, half of which were active. They were relatively short, averaging 0.72 m. Two of the the ten burrows contained bones.

A few small pockets of active burrows were found on the south side of Cohoe Point, usually at the base of large trees or steep slopes. Spruce cone chewings were a common sight and one chewed skull was found above the ground. As I progressed west towards Egeria Bay I found a large area that looked like old nesting habitat (in the vicinity of transect 12 of the 1981 survey). Unoccupied burrows containing eggshell membrane, old salal (Gaultheria shallon) leaves, bones and rodent chewings were discovered. No sign of nesting activity was found however; the area was abandoned.

I also made a quick (30 minute) exploration of the colony area west of Henslung Cove, reported from the 1981 survey. There were no signs of breeding activity there. Instead I found abandoned burrows containing old eggshell membrane, old salal leaves (reported as common nest material for Ancient Murrelets

by Sealy 1976), bones and fresh rodent chewings.

Although we did not visit the small colony reported west of Fury Bay (active in 1981), Wayne Nelson (pers. comm.) found fresh, dead Ancient Murrelet chicks in a cave beneath a steep cliff in that area. Those chicks, who presumably perished while departing, are evidence of recent breeding activity in the area.

The extent of the Ancient Murrelet colony in 1988 was much smaller than the colony found in 1981 (Figure 3.4). Table 3.3 compares census results from 1981 and 1988. In 1988, the colony area was less than half the 1981 level. Although the estimated number of burrows was 20,000 higher in 1981, the final population estimates were similar (21,500 and 24,100 for 1981 and 1988 respectively) owing to the higher burrow density in 1988. Burrow occupancy rates were similar in both years (Table 3.3).

Of the eight transects performed in both 1981 and 1988, only four still had active burrowing in 1988. Table 3.4 compares those transects in the two years. In 1988, three of the four transects extended further than they did in 1981, suggesting that the colony may have expanded slightly in those regions. The number of burrows found along the transects in 1988 was also significantly higher than in 1981. A Mann-Whitney test showed no difference in burrow density, however. There was also no difference in burrow occupancy rate.

Figure 3.4: The extent of the Ancient Murrelet colony on Langara Island in 1981 (adapted from Rodway et al. 1983) and 1988. The colony reported west of Fury Bay in 1981 was assumed to be active in 1988 (see text).

Table 3.3: A comparison of the census results from 1981 and 1988. Occ. rate represents the burrow occupancy rate. n = the number of quadrats sampled in each year. The calculations for the 1988 population estimate are shown in Appendix 3.

Year	Colony area (ha.)	Burrow density (burrows/m^2)			Estimated total burrows		Occ. rate (%)	Population Estimate	
		Mean	S.E.	n	Total	S.E.		Pairs	S.E.
1981	108	0.082 *	0.014	39	83,000	14,000	26 **	21,500	3,600
1988	46	0.135	0.023	31	63,000	10,500	38	24,100	4,000

* = significantly different: t = -2.62, df = 51.4, P = 0.049
** = no difference based on a χ^2 test of the number of occupied and unoccupied burrows in each year

Table 3.4: A comparison of occupancy rate and the number of burrrows in 5 m x 5 m quadrats along the same transects run in 1981 (Rodway et al ., 1983) and in 1988. * = quadrat deemed out of colony boundary.

Transect number		Quadrat number	Number of burrows		Burrow end reached		Occupied burrows	
1981	1988		1981	1988	1981	1988	1981	1988
4	9	1	1	0	0	0	-	-
		2	2	4	0	1	-	0
		3	0	2	0	0	-	-
		4	2	4	2	0	1	-
		5	1	2	1	1	0	1
		6	*	2	0	1	-	1
5	3	2	1	0	0	0	-	-
		3	1	0	1	0	0	-
		4	4	1	4	0	3	-
		5	2	16	2	3	1	1
		6	*	6	-	0	-	-
6	1	1	12	1	4	0	1	-
		2	0	8	0	0	-	-
		3	1	5	0	0	-	-
		4	2	3	0	1	-	-
		5	*	5	-	1	-	0
		6	*	1	-	0	-	-
7	4	1	0	0	0	0	-	-
		2	0	0	0	0	-	-
		3	0	2	0	2	-	0
		4	8	1	2	0	0	-
		5	4	6	1	5	1	2
		6	3	0	0	0	-	-
		Totals	44	† 72	17	15	7 ‡	5

† = significantly different: $\chi^2=6.78$, df = 1, $P < 0.01$
‡ = no difference in occupancy rate based on a χ^2 test comparing the number of occupied and unoccupied burrows in each year

3.2 Knock-down plots

Following the 15 day monitoring of knock-downs, sections of each of four plots were excavated to determine the actual number of burrows present. Table 3.5 summarizes the results of that effort. The accuracy with which burrows were identified (and marked) previous to monitoring ranged from excellent to poor. In plot 1 no burrows were misidentified or overlooked. However, in plot 3, two burrows were marked that actually were not burrows but tunnels that led to dead ends. In addition, seven burrows were overlooked during the erection of that plot, probably due to an inexperienced observer. In all plots the 10 m x 10 m quarter excavated contained between 12-16 burrows (Table 3.5).

Since only a portion of knock-down plots were excavated, I did not remove non-burrows from the list of monitored burrows in each plot. It is noteworthy, however, that knock-downs frequently occurred at non-burrows (Appendix 4) because tooth picks were occasionally placed at the entrance to a tunnel that was a route to one or more burrows.

The average proportion of knock-downs per night ranged from 21% in plot 4 to 39% in plot 2 (Table 3.6). Overall, the average proportion of knock-downs in plots 4 and 5 were significantly lower than the other four plots. Those differences did not appear to relate to the density of burrows in each plot.

Despite differences in the visitation rates the day-to-day pattern of knock-downs was similar among plots. Although large

Table 3.5: The actual number of burrows in the excavated quarters of the knock-down plots. The total includes overlooked burrows less cavities mistaken for burrows.

Plot #	Study sample	Non-burrows and cavities	True burrows in sample	Overlooked burrows	Total number of burrows
1	14	0	14	0	14
3	7	2	5	7	12
4	12	2	10	6	16
5	9	1	8	5	13

Table 3.6: Analysis of variance and multiple range tests of the proportion of "burrows" entered in the six knock-down plots on 15 consecutive nights beginning on 15 May. The analysis was performed on arcsin square root transformed data but the means and S.D. presented have been back-transformed to proportions. The same letter beside the means indicates no significant difference in the proportion of knock-downs per night, based on a Student-Newman-Kuels multiple range test (MRT). * = groups significantly different with $\alpha = 0.05$.

Plot	MRT	Mean	S.D.	Number of burrows	Burrow density b/m^2	F	P
1	a	0.33	0.02	68	0.17		
2	a	0.39	0.03	40	0.10		
3	a	0.38	0.02	72	0.18	4.91	0.0005 *
4	b	0.21	0.02	64	0.16		
5	b	0.27	0.02	51	0.13		
6	a	0.32	0.02	43	0.11		

day-to-day variation was common, a pattern of peaks of activity, followed by periods of diminished activity, appeared to repeat itself in all plots (Figure 3.5). Moreover, the lowest proportion of knock-downs occurred, in all plots, on 21 or 22 May. Figure 3.6, which combines the data from all plots, shows the extreme variation in the proportion of burrows entered daily.

3.3 Staging count

The number of birds staging nightly in May ranged from 5 to 4,620. (Figure 3.7). On nights when very few birds were seen, observation conditions were generally poor. Visibility was often reduced by rain, and wave action frequently obscured birds from sight. I attempted to monitor and record weather conditions at observation times by listening to the local weather report from the light station on Langara Point (65 m above sea level). However, inconsistencies between weather reports and actual conditions at McPherson Point forced me to abandon weather monitoring. Overall there was a trend for the number of staging birds to increase as the season progressed (Figure 3.7).

There was a significant positive relationship between the number of birds observed staging and the total number of knock-downs discovered on the plots the following day (Figure 3.8). This suggests that staging counts provide an index to colony activity on a given night.

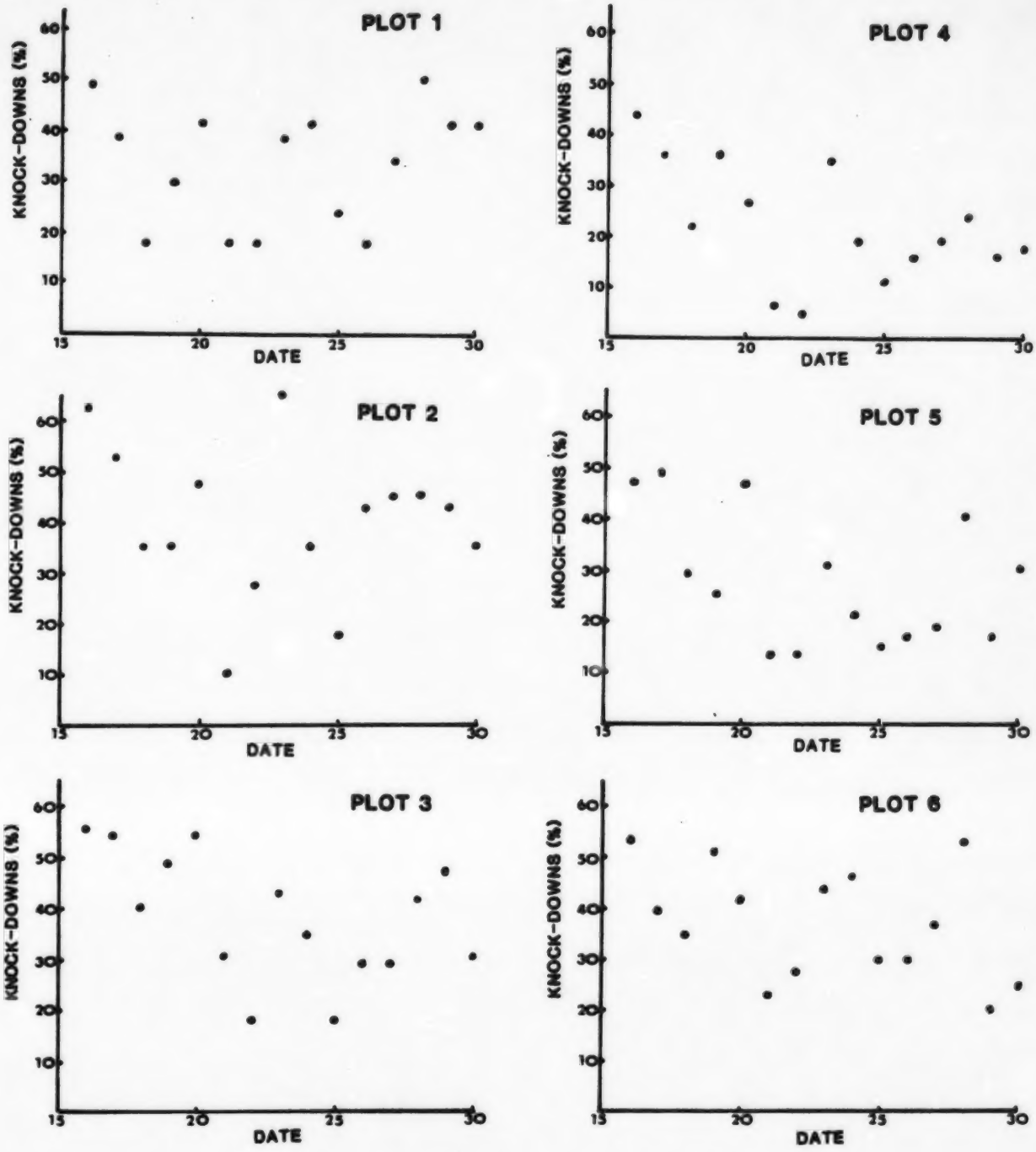


Figure 3.5: Day to day variation in the proportion of burrows entered in the six knock-down plots during May.

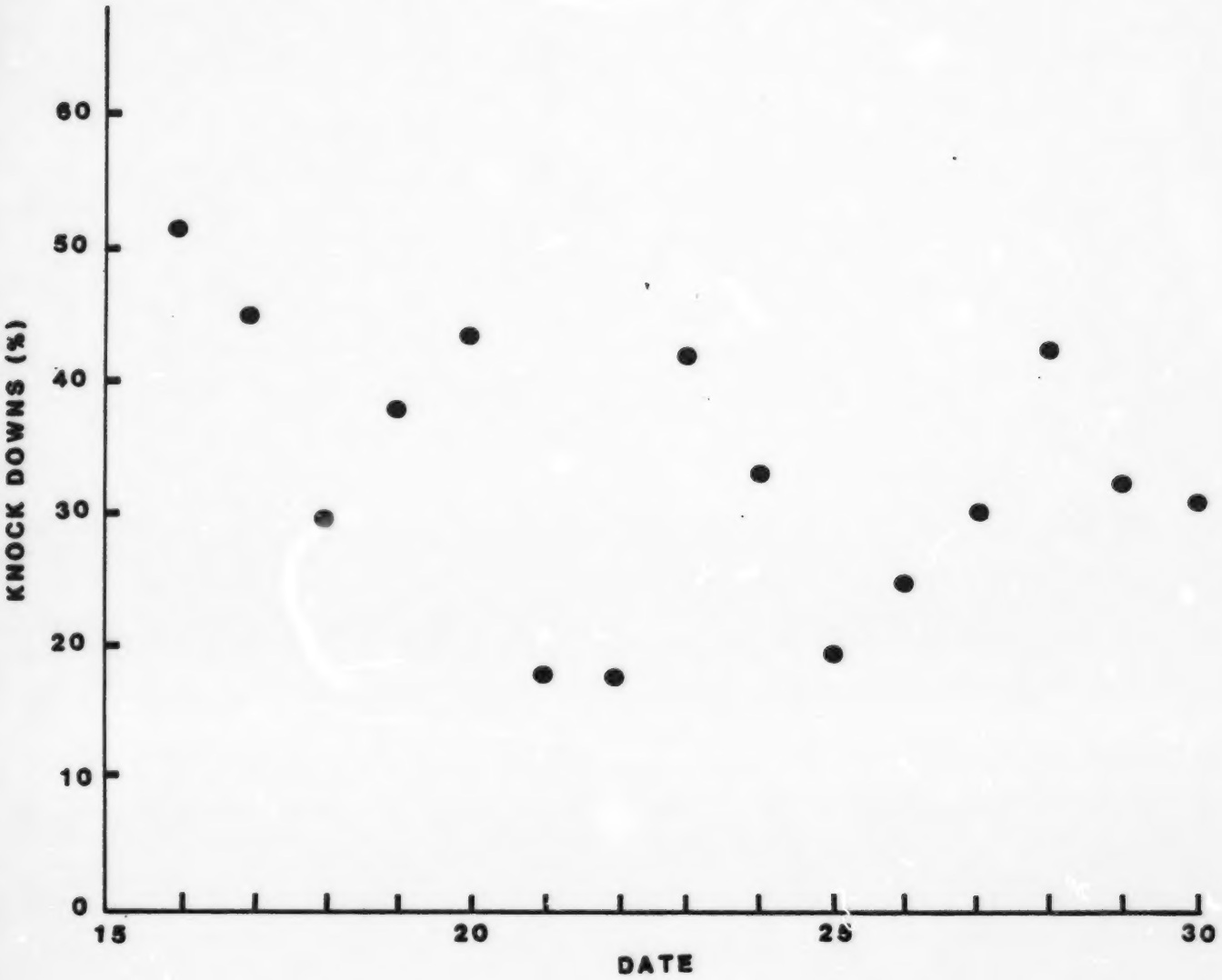


Figure 3.6: Day to day variation in the proportion of burrows (n = 338) entered during May. The data was combined from all six knock-down plots.

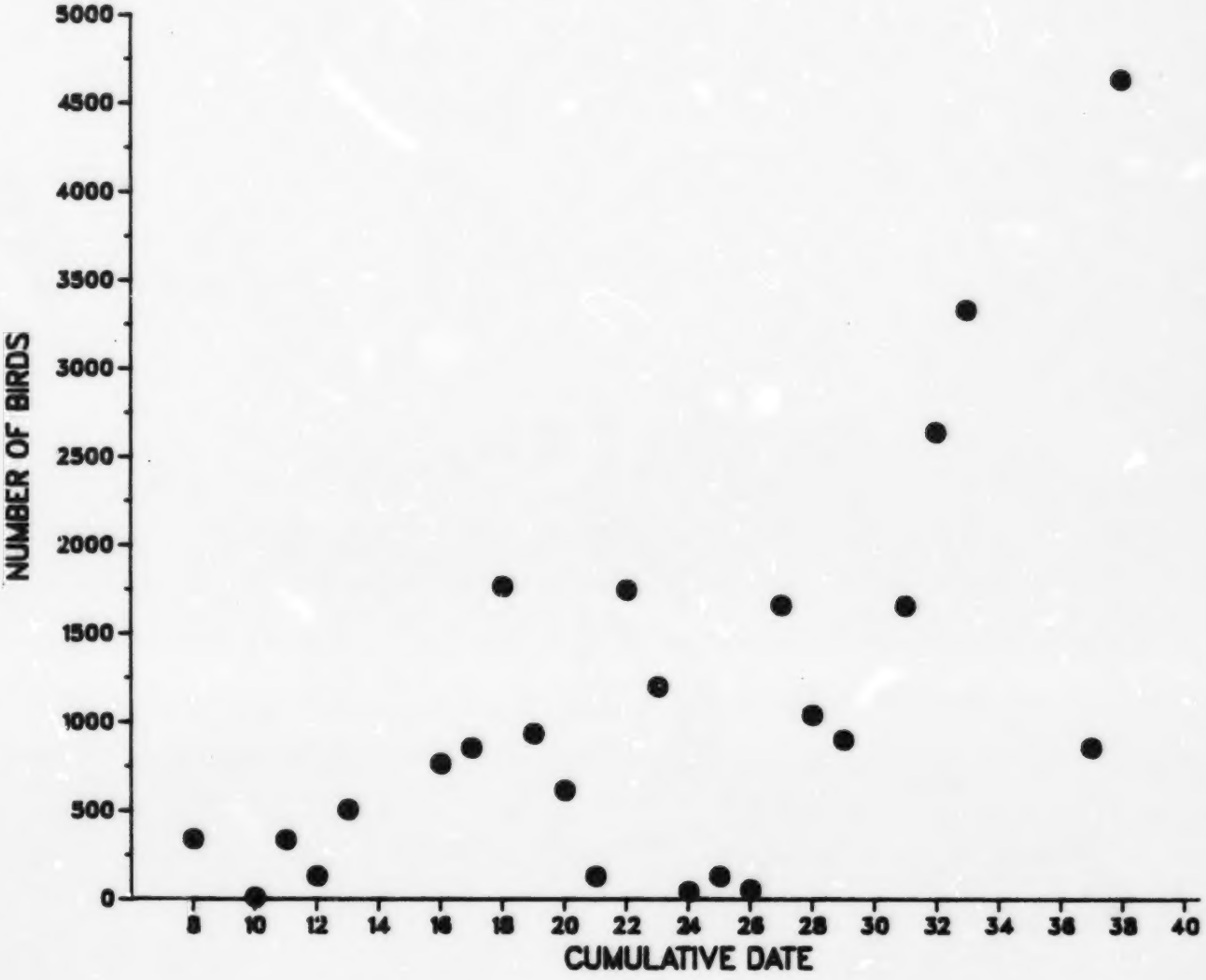


Figure 3.7: The number of birds seen staging during nightly 10 minute counts with a telescope. The date begins on 8 May.

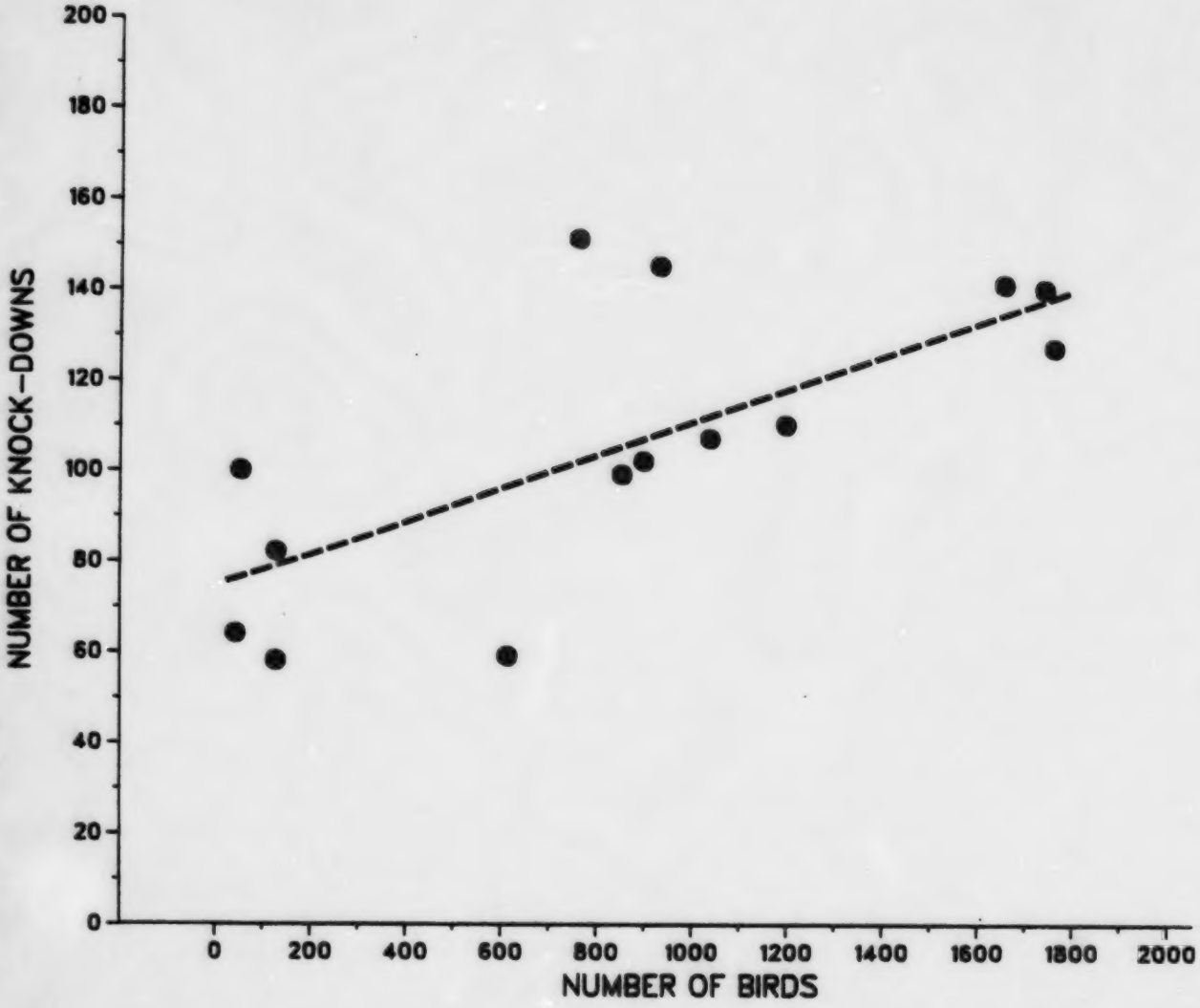


Figure 3.8: The number of birds seen during the nightly staging count (X) in relation to the number of knock-downs (all plots combined) the following day (Y). The relationship, $Y = 74.8 + 0.037(X)$, is significant ($F = 12.2$, $df = 1,12$, $P < 0.005$, $R^2 = 0.46$).

3.4 Incubation initiation and chick departure weight

The estimated mean date of the start of incubation for Ancient Murrelets on Langara was 1 May (Appendix 5). The lower and upper confidence intervals for this estimate were 27 April and 8 May respectively. Incubation initiation dates for eggs found pipping [assumed to have been incubated for 32 days (Collins and Gaston 1987)] also fell within that range.

Unfortunately, the performance of the electronic counter attached to the base of the chick funnel was unreliable. During 24 and 29 May the counter read between zero and five the morning following operation. These figures were probably accurate. However, on 1, 3, 4 and 6 June the counter read 1323, 586, 619 and 728 respectively. Those numbers were surely artificial since only 30 chicks were seen at the funnel exit during the weighing session of 31 May (17 were weighed). Likewise only 14 birds were caught on 2 June and only six the night of 6 June. Further testing showed that the counter jumped by several hundred if there was not at least one second between events.

On the nights that we weighed departing chicks, movements began around midnight, peaked near 01:00 hrs and generally stopped by 02:30 hrs. Chick weights ranged from 21.5 g to 29.0 g (Table 3.7). No difference was found between the weights of chicks departing on various nights. However, departure activity decreased from 31 May to 6 June.

Table 3.7: Analysis of variance of weights of Ancient Murrelet chicks departing on different nights.

Date	n	Mean weight	S.D.	Min	Max	F	P
31 May	17	26.1	1.8	22.5	28.5		
2 June	14	24.9	1.9	21.5	29.0	2.14	0.133
6 June	6	24.8	1.9	23.0	27.0		
Totals	37	25.4†	1.9	21.5†	29.0†		

† Average value

3.5 Predation

Spruce cone chewings, assumed to be left by rats, were found throughout the colony as well as in areas that appeared abandoned. One pile of chewings, discovered in a decayed stump along transect 15, was very large and contained the remains of at least 50 cones, in addition to an Ancient Murrelet sternum. Along the same transect I also found rat footprints in soft mud and a recently active den along the vegetation edge among driftwood. Turning a few small logs allowed me to inspect the inside of the den. At the end of a 1.5 m tunnel was a nest cavity full of grass and pieces of chewed orange plastic. There was an abundance of fresh rusty-brown dung in one place in the tunnel and a distinct pungent smell prevailed. Signs of rat activity were also found close to driftwood piles in the bay on the north side of McPherson Point.

The first rat trapped on 12 May was an adult female with prominent teats. The trap was within 5 m of the vegetation edge along a well worn trail. Abandoned burrows were located within 10 m of the trap site and one that was investigated contained bones. In total four additional rats were trapped throughout the course of our study - 3 young of the year and one other adult (Table 3.8).

The only live rat seen in the wild was observed with a flashlight at 23:15 hrs on 26 May near the exit to the chick funnel. As I approached the funnel exit the rat came up from the

Table 3.8: Dates on which rats were trapped and the baits used to attract them. Pb = peanut butter; Hh = hamburger and herring; C = chicken.

Date	Bait	Weight (g)	Length (cm)	Sex	Trap type
12 May	Pb	352	38.4	F	Snap
31 May	Hh	90	26.6	M	Snap
5 June	Hh	115	29.0	M	Snap
7 June	Hh	122	29.0	F	Snap
7 June	C	299	38.0	F	Live

"beach" rocks at the vegetation edge and began to climb up the forested slope towards the colony. When I shone the light beam on the rat, it darted into what appeared to be an old burrow and remained there.

On 9 May, on transect 1, two freshly killed Ancient Murrelets were found in a burrow, within 15 cm of each other. Both birds had open, bloody wounds to the region near the back of the neck - likely the cause of death. The birds weights were 185 g and 189 g, neither had brood patches. Old bones were also discovered in the same burrow. A similar finding occurred on 18 May along transect 10. A fresh, dead Ancient Murrelet was found in the mouth of a burrow with an open wound from the base of the skull at the back of the neck to the pectoral girdle. Within 2 m, another kill was located with a similar gaping wound to the upper back near the pectoral girdle. Only one of the two birds had brood patches. Finally, on 22 May, while exploring the area around transect 14 two more such kills were discovered. Those birds, however, were not fresh and may have been dead for over a month. One carcass had the skull chewed open and the upper abdomen eaten. The other, further in along the same cavity (under a log), had its skull intact.

In addition to recording depredated eggs along the transects, we searched for them in the knock-down plots. On 30 May two such eggs were found in plot 5. The eggs, found within one m of a burrow, were largely intact but both had holes (3 cm x 2 cm) along the top that appeared to have resulted from

chewing. Neither egg showed signs of incubation and both still contained roughly half of their contents (including most of the yolk). Bits of shell lay scattered around the eggs. No signs of scrape marks, indicative of avian predators such as crows, were visible inside the eggs.

Between 18 May and 6 June only one egg of the 13 experimental chicken egg clutches was depredated. On 22 May, the cracked egg of an experimental clutch was found opened on one side. The hole size and general appearance was very similar to the freshly depredated eggs found in occupancy plot 5 on 30 May, however the egg contents had spilled out.

4. DISCUSSION

The most striking outcome of the survey was the large decline in colony extent in 1988 to less than half the size reported in 1981 (Table 3.1, Figure 3.4). Despite the dramatic change in colony area however, the population estimates were of the same magnitude: 24,100 +/- 4,000 pairs in 1988 and 21,500 +/- 3,600 in 1981. Unfortunately, the accuracy of the survey technique is low, as evidenced by the large degree of variability in the estimates. Ninety-five percent confidence intervals for 1981 and 1988 are 24,100 +/- 8,000 and 21,500 +/- 7,500 respectively. This means that there is a 95% chance that the real population was between 15,000 - 29,000 in 1981 and 16,000 - 32,000 in 1988. As such it is impossible to tell if the population size has changed, given the census technique employed.

Aside from estimating colony area, there are two other parameters needed to calculate the population estimate - burrow density and burrow occupancy rate. For the population estimates in 1981 and 1988 to be similar, despite a large decline in colony area, burrow density, burrow occupancy rate, or both parameters must have increased.

Although I found no change in burrow density on the four transects performed in both years, the colony extent in 1988 was generally wider and there were significantly more burrows along the transects than in 1981 (Table 3.4). When a larger analysis,

comparing all of quadrats layed out in surveys was performed, I found that burrow density was significantly higher in 1988 than 1981 (Table 3.3).

Burrow occupancy rates were similar in 1981 (26%) and 1988 (38%). However, those estimates were based on very small sample sizes - 0.04% of all nests in the colony in 1988 and 0.05% in 1981. An additional problem with the estimate is that it assumes uniformity of occupancy rates throughout the colony. Furthermore, the occupancy rate is not assigned an error term. Thus, the final population estimates should have larger S.E. than shown. One final problem with the estimate of occupancy rate is the potential for bias due to the way it is established. Only burrows whose ends can be reached are used in the calculation. Therefore burrows which extend under tree roots, stumps or rocks are not sampled. Regardless, they are assumed to have the same occupancy rate as accessible burrows.

Given the inaccuracies associated with the measure of burrow occupancy rate, it may be instructive to compare the estimated total number of burrows in the two surveys. The estimated total number of burrows was 83,000 +/- 14,000 in 1981 and 63,000 +/- 10,500 in 1988 (Table 3.3). Those figures, in conjunction with the large change in colony area, and higher burrow density, suggest that the population size has declined since 1981 to yield a smaller, more dense colony in 1988.

Since 1981, the colony area south of transect 4 has become almost entirely abandoned (Figure 3.1, Table 3.1). Although this

represents a large scale loss, in a relatively short period of time, close examination reveals that abandonment may have occurred over a longer time frame. On Rodway et al.'s (1983) map of the colony, the area south of transect 7 (my transect 4) shows continuous burrowing, at three density levels. However, with the exception of the transect on the south side of Cohoe Point, there are no records of occupied burrows for the entire area. In this type of census the sampling unit is a 5 m x 5 m quadrat. Decisions on the location of colony boundaries are dependent on what is found within those quadrats. However, since the sampling unit is so small, active burrows (or burrows whose occupancy can be determined) may not be found in a quadrat even if the transect is running through an active part of the colony. In such a case, signs of activity such as burrows, feather piles and depredated eggs seen adjacent to the quadrat are used to decide if that quadrat represents an active burrowing area. That feather piles and depredated eggs act as an indicator of occupied burrows in an area is shown in Figure 3.3. The technique is subjective however: how many continuous quadrats with no occupied burrows can be said to represent active burrowing areas because feather piles were seen along the transect? Since no occupied burrows were found in the area south of transect 4 to the south side of Dibrell Bay in 1981 it is likely that the area was on the verge of abandonment at that time. Thus, the decline in colony extent is not as dramatic as might be presumed if only the maps from 1981 and 1988 are compared.

Despite the unclear changes in nesting activity on part of Langara Island, some areas, obviously active in 1981, were completely abandoned in 1988. In 1981, transect 12, on the south side of Cohoe Point, had 13 burrows in six quadrats and 3 of 12 were occupied (Rodway et al. 1983). In 1988 I explored the area by foot and found no burrowing activity, feather piles or depredated eggs. Similarly, the area behind McPherson Point, which was reported to have high densities of Ancient Murrelet burrows was devoid of active burrows (transects 13 and 14) in 1988 although burrow density was among the highest discovered during the survey (Table 3.1; Note that although this area was not transected in 1981 transects on either side of it contained active burrowing at high densities). Thus, colony extent has indeed diminished.

Why has the colony extent declined? This study suggests that rats could have played a role. Although we never saw a rat kill a murrelet, the dead birds found underground, with wounds that appear to have been inflicted by rats (B. Foster, pers. comm.), are compelling evidence. Other descriptions of adult murrelets found dead in burrows with similar wounds have been reported by previous workers on Langara (Sealy 1976; Vermeer et al. 1984; R.B.C.M. unpublished seabird survey data, 1977).

The adult rats trapped were roughly 1.5 times heavier than adult murrelets. This size difference makes it likely that rats on Langara are easily capable of killing adult Ancient Murrelets. Alexandrian rats are reported to eat their food

undercover (Hart 1982). On Langara, rats venturing into burrows to eat spruce cones (many burrows contained them) may encounter Ancient Murrelets. In the narrow confines of the burrow walls a bird could easily be 'cornered' and killed. Through such opportunistic killings rats may quickly learn of the profitable food source to be found in the numerous burrows on the island. Dead birds in burrows also last for a considerable length of time due to the cool temperatures underground, even in summer months on Langara. Thus, rats could cache murrelets during the breeding season and feed on them during later months.

This scenario is further supported by the high proportion of bones (29%, Table 3.1) found in burrows throughout the colony. Reports of bones in burrows on other Ancient Murrelet colonies are rare. Lyell Island, where rat (Rattus rattus; A. Harestad, pers. comm.) skeletal remains were found is the only other colony where murrelet bones have been reported (Rodway et al. 1988). Five of 92 (5%) burrows found on Lyell contained bones. In addition to rat droppings found in burrows, four dead Ancient Murrelet carcasses were found with chew marks on the necks and upper breast areas. Caches of eggshells were also found under tree bases and stumps (M. Rodway pers. comm.). Not only does Langara have the highest proportion of burrows containing bones per colony, the proportion of such burrows is greatest in abandoned areas of the colony and lowest where the burrow occupancy rate is greatest (Figure 3.2). This further implicates rats as a possible cause for the decline in colony extent.

Disturbance of nests by rats may also contribute to the abandonment of some areas (Table 3.1) and increased burrow density in others (Table 3.3). Gaston et al. (1988) show that a high proportion of Ancient Murrelet burrows (21%) may be deserted as a result of only a single direct inspection. It is possible that an encounter with a rat may also lead to desertion, if the bird lives. Thus, birds may leave areas where rats are present and choose to breed the following year at other locations (which become increasingly dense) where rats are less abundant. (Note that while disturbance by biologists surveying the colony on Langara has inevitably lead to desertion of some nests, it is unlikely that their activities have been responsible for abandonment of vast areas of colony due to the small number of nests excavated).

The possibility of rat-induced desertion represents an insidious problem that may take a very slow toll on the population. Deserted eggs, whether they are eaten by a rat or not, represent a failed breeding attempt. Regular desertions during each breeding season may therefore lead to diminished reproductive success for the population as a whole, and over time lead to a gradual decline due to reduced recruitment. This scenario is intensified when one considers the potential loss of fledglings to rat predation.

One aspect that remains to be examined is the effect of changes in nesting density and colony size on adult survivorship in relation to avian predation rate. This could be particularly

informative on Langara Island, where the level of avian predation, relative to population size, is reported to be 3.5 times higher than Frederick Island, the largest Ancient Murrelet colony in B.C. (Vermeer et al. 1984). To date, there have been no detailed investigations of the relative rates of predation by Peregrine Falcons, Bald Eagles (Haliaeetus leucocephalus), and Common Ravens (Corvus corax) on Ancient Murrelets nesting on different colonies. Such information is a necessary component to elucidating the population dynamics not only of the Ancient Murrelets but also of the predators that feed on them.

Although rats on Langara have been implicated as predators on Ancient Murrelet eggs (Campbell 1968; Sealy 1976), adults (Sealy 1976; R.B.C.M., unpublished seabird survey data, 1977; Vermeer et al. 1984), and chicks (Sealy 1976) they have been largely overlooked as a serious threat to the population. Sealy (1976) considered depredation of murrelets by rats to be "negligible" while Nelson and Myres (1976) regarded rats not to be of "major importance" in reducing murrelet numbers, except on a local scale. That view was also adopted by Vermeer et al. (1984). It is noteworthy that two of the areas where rats were suspected of preying on murrelets - above Iphigenia Point and south of Egeria Bay - were either abandoned in 1981 (Egeria Bay) or by 1988 (Iphigenia Point).

Although the Ancient Murrelet population on Langara may have suffered heavy losses due to adult mortality resulting from commercial fishing operations in the colony vicinity during the

1950's and 1960's (Shelford 1988; C. Bellis's letter to the 1988 Falcon Inquiry reports gill net drownings and deaths from striking guy wires of lighted boats), the results of this study suggest that rats may also have been important. While the population estimates for 1981 and 1988 are similar, the comparison is inconclusive because of the low accuracy of the census technique. The lower total number of burrows, and smaller colony size in 1988 (Table 3.3), however, suggest the population size has decreased. Given the apparent ubiquitous distribution of rats (as judged by spruce cone chewings, Table 3.1) throughout the present and former colony, and the rat's opportunistic nature and high reproductive potential (3-7 litters of 6-22 young each per year, Hall and Kelson 1959) the fate of the Ancient Murrelets on Langara Island remains uncertain. While total extinctions of seabird populations have seldom resulted from rat predation (Moors and Atkinson 1984) the extent of the Langara Ancient Murrelet colony may continue to decline.

Wildlife managers are faced with a difficult decision on Langara where an apparent decline in seabird numbers is only circumstantially linked to rat predation. In order to demonstrate a detrimental effect definitively, one must show quantitatively how rat predation and disturbance impact on the bird's natality and mortality schedules. That knowledge would require intensive study similar to the work being conducted on Reef Island. However, the work offers no guarantee that subsequent eradication campaigns against the rats will be

successful. In another five years it may be too late.

Regardless of the course of management action taken on Langara Island, I strongly support the recommendation made by Vermeer and Sealy (1984) that methods of accurately censusing burrow-nesting seabirds be researched. The development of improved census techniques will undoubtedly contribute to future long-term monitoring and management of seabirds in B.C.

5. LITERATURE CITED

Beebe, F.L. 1960. The marine Peregrines of the northwest Pacific coast. Condor 62: 145-189.

Campbell, R.W. 1968. Alexandrian rat predation on Ancient Murrelet eggs. Murrelet 49: 38.

Collins, B.T. 1987. CIIR: A program to calculate confidence intervals on mean date of laying using egg density. Unpublished C.W.S. document. 22 pp.

Collins, B.T. and A.J. Gaston. 1987. Estimating the error involved in using egg density to predict laying dates. Journal of Field Ornithology 58: 464-473.

Cowan, I. McT. and C.J. Guiguet. 1965. The Mammals of British Columbia. Handbook No. 11, Royal British Columbia Museum. 414 pp.

Darcus, S.J. 1930. Notes on the birds of the northern part of the Queen Charlotte Islands in 1927. Canadian Field Naturalist 41: 41 49.

Drent, R.H. and C.J. Guiguet. 1961. A catalog of British Columbia seabird colonies. Occasional Paper Number 12. British Columbia Provincial Museum. Victoria.

Gaston, A.J. and B.T. Collins. 1988. The use of knock-down tags to detect changes in occupancy among burrow-nesting seabirds: What is an adequate sample size? Canadian Wildlife Service Progress Note No. 172.

Gaston, A.J., I.L. Jones and D.G. Noble. 1988. Monitoring Ancient Murrelet breeding populations. Colonial Waterbirds 11: 58-66.

Green, C.B. 1916. Note on the distribution and nesting habits of Falco peregrinus pealei Ridgeway. Ibis 58: 473-476.

Hall, E.R. and K.R. Kelson. 1959. The Mammals of North America. Ronald Press Company, New York. 1162 pp.

Hart, M. 1982. Rats. Allison and Busby, London and New York. 172 pp.

Moors, P.J. and I.A.E. Atkinson. 1984. Predation on seabirds by introduced animals, and factors affecting its severity. (pp. 667-690) In: Status and Conservation of the World's Seabirds. J.P. Croxall, P.G.H. Evans, and R.W. Schreiber (Eds.). International Council for Bird Preservation Technical Publication No. 2.

Nelson, R.W. and M.T. Myres. 1976. Declines in populations of Peregrine Falcons and their seabird prey at Langara Island, British Columbia. Condor 78: 281-293.

Rodway, M., N. Hillis, and L. Langley. 1983 . Nesting population of Ancient Murrelets on Langara Island, British Columbia. Unpublished Canadian Wildlife Service Technical Report.

Rodway, M.S., M.J.F. Lemon, and G.W. Kaiser. 1988. British Columbia Seabird Colony Inventory: Report #1 - East Coast Moresby Island. Technical Report Series No. 50. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

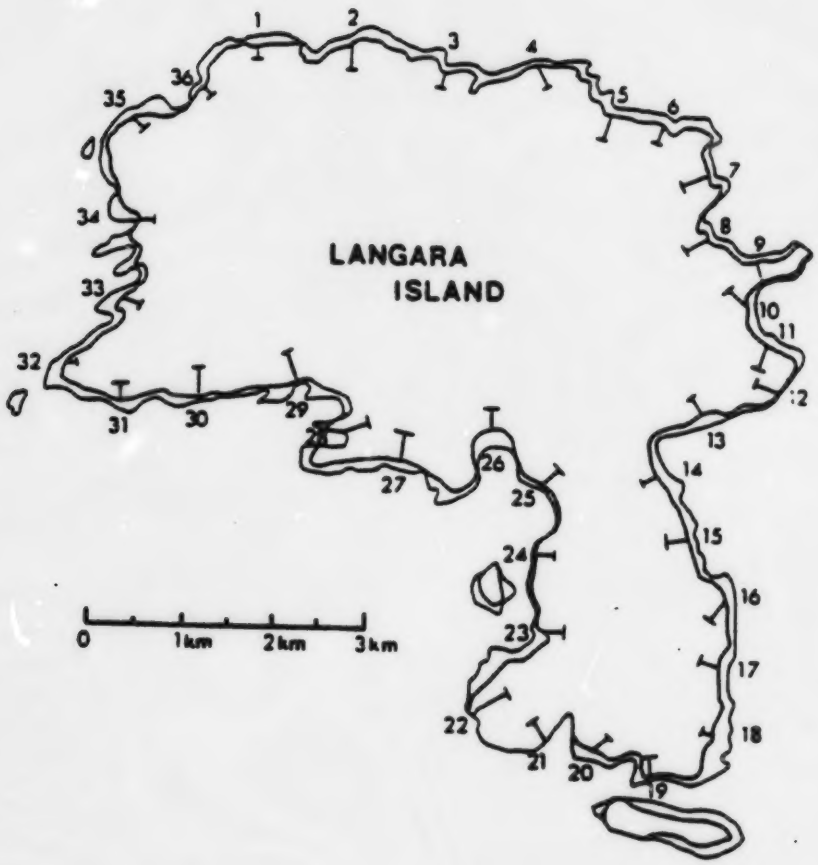
Sealy, S.G. 1976. Biology of nesting Ancient Murrelets. Condor 78: 294-306.

Shelford, C., 1988. The falcon is telling us something. Report of the Committee of the Inquiry on Falcons. Queen's Printer for British Columbia, Victoria. 60 pp.

Vermeer, K., and S.G. Sealy. 1984. Status of nesting seabirds in British Columbia. (pp. 29-40) In: Status and Conservation of the World's Seabirds. J.P. Croxall, P.G.H. Evans, and R.W. Schreiber (Eds.). International Council for Bird Preservation Technical Publication No. 2.

Vermeer, K., S.G. Sealy, M. Lemon and M. Rodway. 1984. Predation and potential environmental perturbances on Ancient Murrelets nesting in British Columbia. (pp. 757-770) In: Status and Conservation of the World's Seabirds. J.P. Croxall, P.G.H. Evans, and R.W. Schreiber (Eds.). International Council for Bird Preservation Technical Publication No. 2.

APPENDIX 1: LOCATION OF TRANSECTS IN 1981



From Rodway et al. 1983.

APPENDIX 2: LOCATION OF TRANSECTS IN 1988

The following table shows the locations of transects run on Langara island in 1988. Transects which were run in 1981 are also listed. Their locations are the same as presented in Rodway et al. (1983). nd = not done in 1981.

Transect number		Bearing	Length of transect	Closest approximate location
1981	1988			
6	1	200	280	1st projecting knoll on W side of bay on N side of McPherson Point
nd	2	200	320	Roughly halfway between transects 1 and 3
5	3	208 (transect was run at 200 in 1981)	280	700 m W of bay on N side of Mcpherson Point
7	4	250	240	S of Mcpherson Point 2nd point N of Explorer Bay
nd	5	240 (switched to 225 at 80 m due to obstruction)	200	Midpoint of NW side of of Explorer Bay
nd	6	208	320	Middle of point NW of Mcpherson Point
8	7	225	280	Explorer Bay 5 m S of creek mouth
nd	8	185	200	S part of Explorer Bay 300 m SE of transect 7
4	9	152	280	West side of point NW of McPherson Point 324° to eastern most Langara Rk.

Transect number		Bearing	Length of transect	Closest approximate location
1981	1988			
nd	10	180	240	East of large cut, bearing 6° to midpoint of most easterly Langara Rk.
3	11	190	200	Halfway between Langara and McPherson Point, bearing 38° to 3 eastern Langara Rk
nd	12	202	160	Large bent spruce tree E of creek near sandy beach
nd	13	250	280	S of S bay on McPherson
nd	14	204	160	W arm of bay W of McPherson Point at 'flower pot' rock
10	15	315	200	Dibrell Bay N of creek in Indian reserve
9	16	343	160	N corner of Dibrell Bay (across point)

APPENDIX 3: POPULATION ESTIMATE FOR 1988

The following calculations employ the same technique used by Rodway et al. (1983) to calculate the number of breeding Ancient Murrelets on Langara Island. The area covered by the colony is calculated by multiplying the length of the burrowing area (determined by following the 100' contour line on a 1:50,000 scale topographical map of the island) by its width (determined by averaging the extent of burrowing, obtained from transects). By multiplying the burrowing area by the average burrow density per quadrat, the number of burrows in the colony and S.E. can be estimated. Multiplying this figure by the overall occupancy rate gives an estimate of the number of occupied burrows or pairs of birds that make up the nesting population in the area transected. Estimates of the number of birds breeding in 'pockets' that were not transected are added to give the total breeding population estimate.

Length of burrowing area:

Length on map = 5.9 cm

Scale of map 1 cm = 500 m

Actual length of burrowing = 5.9 cm x 500 m/cm = 2950 m

Width of burrowing area:

For each transect the colony boundary was assumed to transcend 15 m past the end of the final quadrat containing burrows (ie half way to the next, empty, quadrat).

Transect	Width of burrowing (m)
10	180
9	180
6	140
3	100
2	180
1	220
4	100

Average width = 1100/7 =157 m

Burrow area:

2950 m x 157 m

= 463150 m^2

= 46.3 ha.

Average burrow density (burrows/m^2)

Number of quadrats in colony = 31

Range of densities = 0.0 - 0.64

Mean +/- S.E. = 0.135848 +/- 0.02254

Total number of burrows:

Colony area x burrow density (mean +/- S.E.)

= 62748 +/- 10439

Occupancy rate: (see Table 3.1)

10/26 = 0.38

Nesting population from transecting information (mean +/- S.E.):

Total number of burrows x occupancy rate

= 23,844 +/- 3966

Nesting population on Cohoe Point (not transected):

Approximate nesting area = 20 m x 70 m = 1400 m^2

Burrow density = 10 burrows/25 m^2 = 0.40

Total burrows = nesting area x density = 560

Occupancy rate = 5/10 = 0.50 (Plot B, Table 3.2)

Nesting population = total burrows x occupancy rate = 280

Total nesting population (+/- S.E.):

Estimate from transecting + estimate from Cohoe Point

= 24,124 +/- 3966 or ca. 24,100 +/- 4,000

note: There is no error estimate for the birds nesting on Cohoe Point, but their number was so small in relation to the total population that it is easily encompassed by the overall error estimate.

APPENDIX 4: RAW DATA FROM KNOCK-DOWN PLOTS

The following series of tables summarize the information collected on the six knock-down plots erected in the colony during 1988 (see Figure App.4.1 for loactions). Methodology is outlined in section 2.3. The letters A-O along the top of each table represent monitoring days 1-15, beginning on 16 May. The numbers along the left hand side of each table represent individual burrows. Within the tables a '1' indicates a knock-down at a burrow. The total number of knock-downs are summarized by burrow (rows) and by date (columns). If part of the plot was excavated following the monitoring of knock-downs (see section 2.3) the status of burrows is listed in column 'Q' (OCC = occupied = adult, eggs, chicks, or eggshell membrane and shell remains from freshly hatched eggs; EMP = empty; UNK = unknown; NAB = not a burrow).

Detailed maps of the locations of all burrows in the knock-down plots were made. Those maps, in addition to a description of the locations of the plots are on file in the permanent monitoring plot scheme at the Canadian Wildlife Service office in Delta , B.C. The four corners of the knock-down plots were marked with aluminum or wooden poles wrapped in brightly colored tape. The flags used to mark individual burrows were left standing.

Figure App.4.1: The location of the 20 m x 20 m knock-down plots (1-6) and the 5 m x 5 m exploration plots (A & B) on Langara Island in 1988. The squares depicting the plots are not to scale. The dotted lines represent transects.

Occupancy plot 1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1					1										1	2	
2																0	
3							1		1			1	1		1	5	
4		1	1			1						1		1		5	
5	1	1		1	1		1					1	1			7	
6	1	1	1	1	1			1	1		1	1	1	1	1	12	
7		1			1			1								3	
8	1	1	1	1	1		1	1				1		1	1	10	
9					1			1	1				1			4	
10					1				1							2	
11	1							1	1			1	1			5	UNK
12					1			1	1				1		1	5	OCC
13								1	1				1		1	4	OCC
14																0	EMP
15	1			1						1			1		1	5	OCC
16	1			1				1	1		1	1	1	1	1	9	OCC
17		1											1	1		3	OCC
18																0	EMP
19				1		1				1				1	1	5	EMP
20																0	EMP
21																0	EMP
22	1	1		2			1			1			1	1	1	8	OCC
23																0	EMP
24														1	1	2	
25	1	1			1				1		1	1		1		7	
26	1	1							1		1	1	1	1	1	8	
27	1				1										1	3	
28	1												1		1	3	
29					1	1	1		1		1		1	1		7	
30	1	2	1	1					1			1	1			7	
31																0	
32	1			2	1	1		1	1	1		1	1		1	10	
33	1	1	1	1	1	1		1	1				1	1	1	11	
34									1			1	1	1	1	5	
35	1	1		1			1			1				1	1	7	
36	1							1		1				1		4	
37				1												1	
38	1				1					1		1		1		5	OCC
39													1			1	
40		1			1	1			1	1						5	
41	1	1							1							3	
42																0	
43																0	
44		1			1			1								3	
45													1			1	
46					1											1	
47	1						1		1			1	1			5	
48	1		1		1			1		1	1		1	1	1	9	
49										1						1	
50								1								1	

Occupancy plot 1 cont'd.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
51			1						1	1		1	1	1		6	
52																0	
53													1			1	
54									1	1						2	
55	1			1	1		1	1			1		1			7	
56		1			1			1	1	1			1	1	1	8	
57	1															1	
58	1	1	2	1				1		1			1	1		8	
59	1	1	1	1	2	1		1			1	1	1	1		11	
60	1	1			1			1					1	1		6	
61	1	1		1			1	1	1		1	1	1	1	1	11	
62	1				1	1		1	1			1			1	7	
63	1	1			1	1		1	1			1	1	1	1	10	
64	1	1	1	1	1			1	1			1			1	9	
65	1	1	1	1	1	1	1	1	1			1	1	1	1	13	
66	1	1		2	1	1	1	1	1		1	1	1	1	1	13	
67	1	1	1	1	1	1		1	1	1	1	1	1	1	1	14	
68	1	1								1	1			1	1	6	
69																	
70	33	26	12	20	28	12	11	26	28	16	12	23	34	28	28		

Occupancy plot 2

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		1		1	1			1	1		1		1	1		6
2	1	1		1	1		1	1	1		1	1	1	1	1	12
3										1	1	1		1		4
4	1	1		1	1			1			1			1		7
5									1							1
6	1	1	1	1	1		1	1	1	1	1	1	1	1	1	14
7	3	3	1					1	3			3		1		7
8	2	3	3				2	1	2		1	1	2		2	10
9	1															1
10																0
11																0
12	1	1			1			1		1		1			1	7
13	1	1	1	1	1				1				1	1		8
14	1															1
15																0
16	1				1			1								3
17	1	1						1				1	1			5
18	1	1	1	1	1		1	1	1	1	1	1	1	1	1	14
19								1								1
20								1								1
21	1	1		1	1		1	1	1		1	1	1		1	11
22	1	1	1	1	1		1	1	1		1	1	1	1	1	13
23	1	1	1					1								4
24	1	1	1	1	1		1	1			1	1	1	1	1	12
25	1	1	1	1	1	1		1	1	1			1	1	1	12
26	1		1		1		1	1	1		1	1	1	1	1	11
27	1	1	1	1	1								1	1	1	8
28								1			1			1		3
29	1	1	1	1	1		1	1	1	1		1	1	1	1	13
30		1				1	1	1			1	1	1	1		8
31	2	2						1			1	1				5
32																0
33																0
34	1			1												2
35	2		1				1			1						4
36	1				1			1			1		1			5
37								1			1	1				3
38					1			1				1	1		1	5
39		1			1	1			1				1			5
40	1	1	1	1	1	1		1			1	1		1	1	11
41																
42	25	21	14	14	19	4	11	26	14	7	17	18	18	17	14	

Occupancy plot 3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1			1		1			1	1			1	1	1		7	EMP
2	1	1	1	1	1			1		1		1	1			9	OCC
3	1							1	1							3	MAB
4	1	1		1				1		1	1			1		7	
5	1		1		1											3	
6	1	1		1		2		1	1				1		1	6	OCC
7		1	1	1	1	1	1	1	1		1	1	1	1	1	13	
8																0	
9	2	2	2	2	1	2		3	2	1		1	1	1	1	13	
10				1	1	1		1								4	
11	1	1	1			1							1		1	6	
12					1						1					2	
13	1						1							1	1	4	
14				1	1		1	1						1		5	
15	1		1	1	1											4	
16		1														1	
17	1	1	1		1			1						1		6	
18																0	
19				1	1		1			1	1					5	
20						1			1		1		1	1	1	6	
21					1			1								2	
22	1	1		1										1		4	
23													1			1	
24														1		1	
25		1		1	1				1					1		5	
26	1	1	1	1	1		1	1			1	1	1	1		11	
27	1	1			1						1		1	1		6	
28	1			1			1					1	1	1	1	7	
29	1	1	1		1	1	1	1	1		1		1	1	1	12	
30									1		1			1		3	
31	1		1	1	1			1						1		6	
32	1	1		1	1	1										5	
33	1	1	1	1	1		1				1			1		8	
34	1	1		1	1											4	
35	1	1	2		1	1			1		1	1	1	1		10	
36	2	2	1	2										2	1	6	
37	1	1						1					1			4	
38	2	1		2				2			2		1	1	1	8	
39				1									1		1	3	
40		1	1													2	
41																0	
42	1	1		1	1								1			5	
43	1	1											1			3	
44		1		1		1		1		1		1		1	1	8	
45	1	1		1	1		1	1	1		1	1	1	1	1	12	
46		1		1	1			1	1			1		1	1	8	
47	1			1	1	1		1	1			1	1	1	1	10	
48		1	1		1			1		1	1		1		1	8	
49	1		1		1						1			1		5	
50		1		1		1				1					1	5	

Occupancy plot 3 cont'd.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
51	1	1		1				1		1	1					6	
52	1	1				1		1	1			1				6	
53	3	3	3	1	3	1	1	3	2		3	2	1	1	1	14	
54	1	1	1	1	1								1			6	
55					1								1	1	1	4	
56						1		1								2	
57									1			1	1			3	
58	1	1	1		1	1	1	1	1					2		9	
59						1								1		2	
60	1	1	1	1	1	1		1	1	1	1	1	1	1		13	
61	1	1	1		1	1	1	1	1	1	1	1	1	1		13	
62										1						1	
63	2	1	2	1	1	1		2	1	1						9	
64	1		1		1			1	1		1	1	1	1	1	10	
65			1	1	1				1			1	1			6	WAB
66		1	1	1	1				1				1			6	WAB
67	1			1					1		1					4	
68	1	1		1		1		1		1		1				7	
69			1				1								1	3	WAB
70					1										1	2	EMP
71			1									1				2	UNK
72	1	1	1		1	1			1			1		1		8	
73																	
74	40	39	29	35	39	22	13	31	25	13	21	21	30	34	22		

Occupancy plot 4

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	1	1	1										1		1	5	
2	2	1	1	1	1			1	2		1	1		1	1	11	
3	1	1	1		1				1							5	
4	1	1	1		1			1	1				1		1	6	
5	1			1									1			3	
6	1	1		1	1			1			1			1		7	
7	1	1		1				1	1					1		5	
8			1							1						2	
9	1	1		1	1											4	
10				1												1	
11																0	
12																0	
13																0	
14																0	
15																0	
16														1		1	
17			2	2	2			2			1			1	1	7	
18	1															1	
19		1		1											1	3	
20	1	1	1	1	1			1			1	1	1			9	
21	1	1		1				1			1	1	1		1	8	
22	1	1		1	1			1		1		1	1	1	1	10	
23	1	1					1									3	
24	1															1	
25	1	1	1					1			1		1	1	1	8	
26		1	1													2	
27																0	EMP
28																0	
29		1		1			1			1		1	1			6	
30	1				1					1		1		1		5	OCC
31																0	EMP
32								1				1				UNK	UNK
33																2	NAB
34	1								1							2	EMP
35											1					1	UNK
36					1			1		1		1	1			5	UNK
37	1	1		1	1	1		1	1	1	1	1		1		11	OCC
38	1	1			1	1		1				1				6	OCC
39					1						1					2	
40																0	NAB
41	1		1					1				1				4	OCC
42			1	1				1								3	
43			1										1			2	
44													1			1	
45	1	1		1				1	1						1	6	
46	1			1					1						1	4	
47	1	1		1	1			1	1		1	1	1		1	10	
48	1			1	1											3	
49				1	1	1		1								4	
50																0	

Occupancy plot 4 cont'd.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
51	1				1			1					1			4	
52	1	1		1		1	1	1	1				1	1		9	
53				1												1	
54	1	1		1						1						4	
55																0	
56								1								.	
57																0	
58								1								1	
59																0	
60																0	
61									1							1	
62			1													1	
63	1	1														2	
64		1	1	1					1				1			5	
65																	
66	28	23	14	23	17	4	3	22	12	7	10	12	15	10	11		

Occupancy plot 5

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1					1											1	
2	1				1										1	3	
3		1		1					1		1					4	
4																0	
5		1				1		1	1			1	1	1	1	8	
6		1		1				1							1	4	
7																0	
8				1										1		2	
9								1								1	
10					1			1							1	3	
11	1	1		1	1		1	1		1		1	1	1	1	11	
12	1	1	1	1	1			1				1	1	1	1	10	
13						1					1		1			3	
14															1	1	
15	2	2	1	1	2						1	1	1		1	9	
16		1			1	1		1		1		1	1	1	1	9	
17		1	1				1	1	1				1		1	7	
18								2					1	2	2	4	
19	1	1	1	1	1	1		1	1	1		1	1		1	12	
20	1	1	1	1	1	1		1		1		1	1			10	
21	1	1			1											3	
22	1		1							1	1		2			5	UNK
23	1															1	
24		1		1											1	3	
25		1				1	1									3	
26	1		1	1	1											4	
27		1		1												2	
28	1				1			1		1		1	1			6	
29	1				1				1						1	4	
30		1	1		1		1						2			5	
31		1	1		1		1				1					5	
32	2	1	1										1			4	
33	1	1	1							1			1	1	1	7	OCC
34					1		1									2	EMP
35					1				1		1			1		4	MAB
36	1								1		1				1	4	EMP
37	1	1	1		1			1	1		1		1			8	EMP
38													1	1		2	EMP
39	3				2	1		1	1			2	1			7	UNK
40			1	1												2	OCC
41		1	2		1				1	1			2			6	
42		1			1		1	1				1				5	
43		1														1	
44		1														1	
45	1															1	
46	1				1											2	
47	1				1				1				1			4	
48	1	1	1		1						1		1			6	
49	1															1	
50	1															1	
51	1	1		1				1								4	
52																	
53	24	25	15	13	24	7	7	16	11	8	9	10	21	9	16		

Occupancy plot 6

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	1		1		1			1					1			5
2					1	1				1						3
3	1	3	2	2	3		1	2	2	1	2	2	2	1	1	14
4	1			1										1		3
5	1	1				1		1	1	1	1	1	1	1		10
6																0
7			1		1											2
8					1								1			2
9				1			1	1		1	1					5
10	1	1		1	1				1				1			6
11																0
12				1			1		1							3
13	1		1		1	1						1	1	1		7
14	1			1					1		1					4
15		1					1		1				1	1		5
16	1	1	1	1		1		1	1	1	1	1	1	1	1	13
17				1								1			1	3
18			1	1	1		1		1		1	1				7
19	1	1	1	1	1	1	1	1	1	1			1			11
20	1			1									1			3
21	1	1			1	1		1	1		1	1			1	9
22		1	1	1		1		1	1	1			1			8
23			1		1								1	1		4
24											1					1
25				1							1					2
26	1			1								1	1			4
27			1				1	1	1			1	1			6
28	1	1		1	1			1	1	1			1		1	9
29	1	1	1		1			1	1				1		1	8
30	1												1			2
31	1		1		1			1	1			1			1	7
32	1	1	1		1	1	1		1	1		1	1			10
33	1		1	1		1			1		1	1	1		1	9
34		1		1				1								3
35							1		1							2
36	1	1		1	1			1	1			1	1		1	9
37	1	1		1	1	1	1	1					1		1	9
38	1	1		1	1		1			1	1	1	1			9
39			1				1	1,								3
40										1			1	1	1	4
41		1						1		1	1	1		1		6
42	1	1		1				1	1	1	1	1				8
43	1			1				1								3
44																
45	23	17	15	22	18	10	12	19	20	13	13	16	23	9	11	

APPENDIX 5: ESTIMATED DATE OF THE START OF INCUBATION

CALCULATION OF CONFIDENCE LEVELS USING INVERSE REGRESSION
SIGNIFICANCE LEVEL FOR LIMITS 0.950

PARAMETERS FROM CALIBRATION CURVE

SLOPE OF CALIBRATION CURVE	-0.00238
INTERCEPT OF CALIBRATION CURVE	0.55350
NUMBER OF OBSERVATIONS USED IN CALIBRATION	142
MEAN OF THE AGES USED IN THE CALIBRATION	11.9510
SUM OF THE SQUARES ABOUT THE MEAN OF THE AGES	11142.6600
RESIDUAL MEAN SQUARED ERROR	0.1000000E-04
CRITICAL VALUE FOR T DISTRIBUTION WITH 140 DOF AT THE 0.9875 SIGNIFICANCE LEVEL	2.266

LENGTH OF INCUBATION PERIOD 32 DAYS

OBS.	DAY	LENGTH	BREADTH	VOLUME INDEX	WEIGHT	DENSITY INDEX	LAYING DATE
1	9	5.72	3.66	76.6	42.0	.548139	6.7
2	9	5.61	3.74	78.5	41.0	.522490	- 4.0
3	9	6.09	3.74	85.2	43.5	.510656	- 9.0
4	10	5.84	3.57	74.4	41.0	.550852	8.9
5	10	5.65	3.84	83.3	43.5	.522130	- 3.2
6	10	5.55	3.92	85.3	45.0	.527652	- 0.9
7	10	5.98	3.72	82.8	43.0	.519615	- 4.2
8	11	5.83	3.96	91.4	47.5	.519559	- 3.3
9	11	5.92	3.84	87.3	46.5	.532683	2.3
10	18	6.04	3.91	92.3	46.5	.503573	- 3.0
11	18	5.76	3.90	87.6	45.0	.513642	1.3
12	32	6.05	3.74	84.6	43.0	.508124	12.9
13	32	5.94	3.68	80.4	41.0	.509685	13.6

MEAN OF VOLUME INDEX	83.830
S.D. OF VOLUME INDEX	5.345

ESTIMATED MEAN DATE FOR ONSET OF INCUBATION	1.4
ESTIMATED VARIANCE OF DATE	50.2909
CRITICAL VALUE FOR T DISTRIBUTION WITH 12 DOF AT THE 0.9875 SIGNIFICANCE LEVEL	2.5600

CALIBRATION PORTION OF CONFIDENCE INTERVAL	12.2724	14.0191
SAMPLING PORTION OF CONFIDENCE INTERVAL	-5.0352	5.0352

LOWER CONFIDENCE LIMIT	-4.5
UPPER CONFIDENCE LIMIT	7.3